ASSESSING THE AMERICAN CONFERENCE OF GOVERNMENTAL INDUSTRIAL HYGIENISTS (ACGIH) THRESHOLD LIMIT VALUES (TLV): LIFTING BEYOND 30 DEGREES TORSO ASYMMETRY

A Thesis by

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The following faculty members have examined the final copy of this thesis for form and content, and recommend that it be accepted in partial fulfillment of the requirement for the degree of Master of Science with a major in Industrial Engineering.

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Jeremy Patterson, Committee Member

DEDICATION

To my parents who were of all the supports and motivations which were of great help to me. Also, it is dedicated to my siblings whom I derive the power from. Finally, I dedicate this work to my wife who provided me the care and supports which made this work through

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ABSTRACT

Dynamic lifting jobs result in a risk of low back disorders (LBDs) higher than any other industrial jobs. There are several ergonomics lifting assessment methods used to evaluate OLBD risk in the lifting jobs. The American Conference of Governmental Industrial Hygienists (ACGIH) Threshold Limit Values (TLV) lifting assessment method is one of the assessment tools used to assess the lifting jobs. The ACGIH TLV tool considers factors such as; the vertical height of the lift, horizontal location of the lift, lift frequency and duration, and the load weight. There is a void on ACGIH TLV, in which it does not apply on lifting jobs that involve torso asymmetry greater than 30˚, and the professional judgment is required to suggest the right TLV in such cases.

The objectives of this study are to a) determine the OLBD risk values for lifting jobs that involve torso asymmetry less than 30˚ (i.e. 0, 15, and 30˚) and greater than 30˚ (i.e. 45, 60, 75, and 90˚) and b) adjust the TLV's for lifting jobs with OLBD Risk probability greater than 30% (i.e. moderate risk). Twenty male college students were included in this lifting experiment. The lifting zones in this study were according to the ACGIH TLV third lifting table. The lumbar motion monitor (LMM) device and the Ballet 2.0 software that comes along with the LMM were utilized to collect and analyze the torso kinematics. The software provided OLBD Risk probability value for each lifting task.

The results have shown that the greater the torso asymmetry angle, the higher the OLBD Risk value. Lifting jobs with torso asymmetry greater than 30˚ were in the moderate risk category in all lifting zones. Also, lifting jobs with torso asymmetry within 30˚ were in the moderate risk category only at mid-shin to knuckle zone in both horizontal distances. However, they were in the low risk category only in knuckle to shoulder zone in both horizontal distances. New TLV's were suggested for lifting jobs with a moderate risk of OLBD.

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LIST OF ABBREVIATIONS

ACGIH	American Conference of Governmental Industrial Hygienists
Cm	Centimeter
Deg.	Degree
LMM	Lumbar Motion Monitor
LBD	Low Back Disorder
MMH	Manual Material Handling
MSD	Musculoskeletal Disorder
OLBD	Occupational Low Back Disorder
WMSD	Work-Related Musculoskeletal Disorder
NIOSH	National Institute for Occupational Safety and Health

CHAPTER 1

INTRODUCTION

1.1 Background

In many workplaces, workers are exposed to risk factors on a daily basis that might result in work-related musculoskeletal disorders (WMSDs) that can influence the workers and working productivity by increasing the number of days away from work. According to the U.S. Bureau of Labor Statistics report (BLS) (2011), in 2010, the median number of days away from work for all cases was eight days, while it was 11 days for WMSD's cases of the same year. Most of these WMSDs occurred to the worker's torso and back. In the private sector, more than 284,000 WMSDs cases resulted in days away from work in 2010, and these WMSDs represent about 30 percent of all injuries (BLS, 2011).

Work-related musculoskeletal disorders (WMSDs) not only result in a large number of lost workdays, but they also can be characterized in term of dollars to be paid as compensations for injured workers. In 1989, the average compensation cost was estimated to be about $8,000 per claim for WMSDs in cumulative trauma disorders of the upper extremity (Webster & Snook, 1994). Silverstein and Adams (2007) reported that in Washington State from the year 1997 through 2005, the estimated direct cost of all occupational MSDs that included the neck, back, and upper extremity, was on average about $12,000 per case and a total of $6.8 billion for all instances.

1.2 Occupational Low Back Disorders (OLBDs)

Low back pain (LBP) is most common in workplaces due to occupational factors such as lifting a heavy load weight, long distance between the lift origin and the worker, lifting objects from the mid shin level or below, reaching to objects above the shoulder level, and high lifting frequency. Spengler et al. (1986) showed that in the United States alone between 11 to 13 million individuals suffer LBP annually. They added that most of those LBP were due to occupational factors. In Hong Kong, it was found that about 57% of the population suffer from LBP at least once in their lifetime, and about 42% of the population experienced LBP at least once in the past 12 months (Leung, 1999). Also, according to a Bureau of Labor Statistics report (2011), back injuries represented almost half of the WMSD cases for all occupations with a median of seven days away from work. Nearly 20% of all workers' compensation cases included low back pain and about 40% of the overall cost was spent on OLBDs (Occupational Safety and Health Council, 2005).

1.3 Lifting Assessment Tools

Given the increased risk of OLBD due to manual material handling (MMH) tasks, there was a need to develop lifting assessment methods to help in identifying the risk factors in the MMH jobs. Thus, several assessment tools have been developed to evaluate MMH tasks. Described below are five of more commonly used assessment tools:

- *The Revised 1991 National Institute of Occupational Safety and Health (NIOSH) Lifting Equation*

This method is used to determine a recommended weight limit (RWL) for two-handed lifting tasks that can be lifted by almost all healthy workers without developing any injury to the back. The RWL is the product of the lifted weight with other different multiplier values found in the multiplier tables. Then, the lifting index (LI) can be calculated by dividing the weight actually lifted by the calculated RWL. This LI indicates whether the lifted load is low risk or elevated risk. This method considers factors such as; the horizontal distance and vertical height of the lift/lower, torso asymmetry angle, the load weight, task frequency and duration, and the hand coupling of the lifted load (Waters, Putz-Anderson, Garg, & Fine, 1993).

- *The Washington State Ergonomics Rule Lifting Calculator (WA L&I)*

This assessment method uses two checklists to assess the required job. The first checklist is called caution zone checklist and includes 14 screening items. If none of the screening items were met, the job is considered to be low-risk; otherwise, the second checklist (hazard zone checklist) should be used. This lifting calculator is based on the NIOSH Lifting Equation. However, the recommended weights for this method are higher than those identified in NIOSH Lifting Equation (WAC, 2000a, b).

- *The Liberty Mutual ''Snook'' Lifting Tables*

The Liberty Mutual Lifting Tables are based on a psychophysical evaluation (i.e. heart rate, oxygen consumption, anthropometric characteristics, and worker satisfaction about the job) to determine the proportion of an industrial population that is capable of performing a given lifting, lowering, carrying, pushing, or pulling task. This method takes into account information about the weight to be lifted/lowered, the location of the hands at the origin of the lift/lower, the vertical and horizontal zones of the lift/lower, and the frequency of the lift/lower (Snook & Ciriello, 1991).

- *Ohio BWC Lifting Guidelines*

This assessment method provides guidelines for low risk lifting conditions for workers returning to work after LBP. It includes three lifting guidelines representing safe, medium, and high risk lifting tasks for lifting with three different ranges of torso asymmetry (i.e. 0˚-30˚, 30˚-60˚, and 60˚-90˚) for workers with LBP as well as asymptomatic workers (Ferguson, Marras, & Burr, 2005). This method is supposed to be used for low frequency lifting (i.e. less than one lift per minute).

- *The American Conference of Governmental Industrial Hygienists (ACGIH) Threshold Limit Values (TLV) for Lifting*

The recommended lifting threshold limit values in this method were developed by the American Conference of Governmental Industrial Hygienists. This assessment method aims to provide low risk weights to be lifted by almost all workers who lift at specified lifting weight, frequency, duration, vertical and horizontal destinations, and torso asymmetry angle (ACGIH, 2005).

1.4 The Void in the ACGIH TLV for Lifting

There are some working conditions in which the ACGIH does not provide TLV weights and suggests using professional judgment to identify low risk weights. Asymmetric lifting when the torso is twisted more than 30˚ away from the sagittal plane is one of these conditions that the current TLV's do not apply to (ACGIH, 2007). Thus, there is a need to investigate whether the provided ACGIH TLV's for the lifting tasks with torso asymmetry from 0 to 30 degrees are suitable if lifted with torso asymmetry greater than 30 degrees.

CHAPTER 2

LITERATURE REVIEW

2.1 Occupational Low Back Disorders (OLBD's)

2.1.1 Incidence

Occupational low back disorders (OLBD's) has a high incidence in many industries. According to Klein, Jensen, and Sanderson (1984), about 60 percent of the reported OLBDs were due to manual material handling (MMH) activities in one home appliance chain, where lifting and handling activities contributed to more than 70 percent of back injury compensations (Klein et al., 1984). De Beeck and Hermans (2000) reported that in Europe, more than 25 percent of workers experience back pain, and that about 75 percent of individuals will experience low back pain (LBP) at any period of their life (De Beeck & Hermans, 2000). For those who get injured, it may take them a long time to recover, which increases the number of days lost from work, where it was estimated that about 65 percent of the workers recovered in a period of 6 to 12 weeks (De Beeck & Hermans, 2000). In the United States, LBP is considered to be a major issue resulting from occupational activities, where about 20% of the workers compensation cases represent almost 40% of the total claims cost (Spengler et al., 1986; Webster & Snook, 1994). Frymoyer et al. (1983) surveyed 1221 males of ages between 18 and 55 years, and found that 30 percent (368 participants) have never felt any LBP, 46 percent (565 participants) had or were experiencing mild LBP, and 23.5 percent (288 participants) had or were experiencing severe LBP.

2.1.2 OLBDs Costs

Occupational low back disorders is costly worldwide. In 2008, lost wages and days away from work due to OLBD's cost the United States more than $7 billion annually (Kriebel, Jacobs, Markkanen, & Tickner, 2011). In Europe, cost of OLBD's was estimated to be more than €12 billion (Kriebel et al., 2011). Andersson (1997) showed that back surgery is performed in the United States more than in any other country, where Rubin (2007) showed that the annual costs for OLBDs were estimated to be from $100 to $200 billion in the United States.

2.1.3 Who gets OLBDs?

According to De Beeck and Hermans (2000), agricultural workers; construction workers; carpenters; truck and tractor drivers; cleaners; nurses and nursing assistants, experience high incidence rates of OLBDs. Eurofound (2007) reported the prevalence of OLBDs by industry, where the highest OLBD prevalence were in agriculture and fishing (47%), construction (37%), manufacturing and mining (29%), and transport and communication (27.9%). Several other studies reported the point or annual prevalence of LBP for different sectors. Farmers ranged from 27% to 75% (Kumudini & Hasegawa, 2009; O'Sullivan, Cunningham, & Blake, 2009; Taechasubamorn, Nopkesorn, & Pannarunothai, 2011), drivers ranged from 44% to 74% (Bovenzi, 2009; Rozali et al., 2009), mine workers ranged from 32% to 78% (Bio, Sadhra, Jackson, & Burge, 2007; Sarikaya, Ozdolap, Gümüştasş, & Koç, 2007), construction workers ranged from 20% to 23% (Inaba & Mirbod, 2007; Inaba, Kurokawa, & Mirbod, 2009), and health care workers ranged from 46% to 83% (Minematsu, 2007; Sorensen et al., 2011). NIOSH (1997b) found that there was strong epidemiological evidence of an association between OLBD and lifting, forceful movements and whole body vibration. Also, there was epidemiological evidence relating an OLBD with awkward postures and heavy physical work (NIOSH, 1997b).

2.2 Factors Contributing to OLBDs

2.2.1 Manual Material Handling

Manual material handling (MMH), especially lifting tasks, are a common contributor of many OLBD's (Kraus, Schaffer, McArthur, & Peek-Asa, 1997), and often includes lifting/lowering heavy objects from/to far (horizontally) surfaces from the worker's body. A study conducted by

Dempsey (2003) found that almost 90 percent of workers lift and/or lower objects weighting more than 3.6 kg and less than 20 kg, with a vertical height at the origin between 35.6 and 104 cm for lifting, and 71 and 152.4 cm for lowering, respectively. According to NIOSH (1997b), a combination of the lifted weight and the worker's technique of handling the object's mass is responsible for the strains level at the low back during manual material handling. The internal reaction forces such as muscle contraction, ligaments, and body joints are needed to counteract the body weight and the external forces (i.e. the lifted loads) (NIOSH, 1997b). However, these supporting tissues can be damaged if the forces due to the lifted weight, body posture, and torso motions create rotational, compressive, or shear forces that are higher than the tolerance of the intervertebral discs and supporting tissues required to counteract the load moments (NIOSH, 1997b).

2.2.2 Torso Flexion

Torso flexion is a risk factor in which the increase in the degree of the torso flexion (Marras et al., 1993 and Norman et al., 1998) and duration of the torso flexion (Hoogendoorn et al., 2000; Punnett, Fine, Keyserling, Herrin, & Chaffin, 1991) increases the risk of OLBD's. Early epidemiologic studies identified torso flexion as a critical risk factor for OLBDs (Kelsey, Githens, & White, 1984; Punnett et al., 1991). As torso flexion increases, the intervertebral disc shear forces increase (Fathallah, Marras, Parnianpour, & Granata, 1998), and the spinal and extensor muscles resistance to the external loads becomes lower during the torso flexion, resulting in greater compression and shear forces being experienced by the intervertebral disks (Van Dieen, Hoozemans, & Toussaint, 1999).

2.2.3 External Load Moment

The greater the distance between the lifted load and the L5/S1 intervertebral disc, the greater the external moment arm (distance between L5/S1 and the load in the hands) will be which increases the internal moment. This results in an increase of the torso muscle coactivity and compression and shear forces on the spine. Marras et al. (1995) described that most of the forces applied to the L5/S1 intervertebral disc are due to the forces generated by the muscle as a result of the increasing distance between the L5/S1 and the external load, which is called the external load moment. Additionally, spinal compressive forces and shear forces increase due to the internal moment developed to counteract the external load moment (Davis & Heaney, 2000; Norman et al., 1998). Finally, the maximum external load moment is considered to be the best predictor of the high risk group membership for OLBD (Marras et al., 1993; Marras et al., 1995).

2.2.4 Torso Twisting

According to NIOSH (1997b), twisting denotes torso rotation in the transverse plane. Twisting the torso while lifting is another factor that contributes to OLBDs. The risk is correlated with the torso movement speed and degree of deviation from non-neutral position sagittally symmetric (NIOSH, 1997b). Kelsey et al. (1984) found that lifting without twisting the body increased the risk of OLBD if it was performed more than 25 times per day (OR = 3.5, 95% CI: 1.5-8.5); however, lifting while twisting the body has an injurious risk of a prolapsed disk no matter how frequent the lift is (OR = 2.7, 95% CI: 0.9-7.9) for lifting with knees are bent. The risk increases with the increase of the lifting frequency (e.g. > 25 lifts per day) (OR = 3.1, 95% CI: 1.3-7.5).

2.2.4.1 Mechanism of Twisting

Twisting of the torso is accomplished by a coactivated effort of many torso muscles, including the internal and external oblique and latissimus dorsi muscles. Marras, Davis, and Granata (1998) assessed the twisting torque and torso muscles activities during upright twisting, twisting while the torso was flexed in the sagittal plane, and twisting while the torso was flexed and rotated asymmetrically. In an upright twisting, the internal and external oblique and latissimus dorsi muscles were involved. However, an increase of 15 and 4 percent of both erector spine and external oblique muscle activities, respectively, was observed while twisting when the torso is being flexed. This increase in the muscle coactivation during twisting in flexed postures also resulted in increased compression and shear forces on the L5/S1 intervertebral disk (Marras et al., 1998), thus, increasing the risk of injury.

2.2.4.2 Epidemiological Evidence of Twisting and OLBDs

Epidemiological studies have shown a relationship between twisting of the torso during occupational activities and an increased risk of OLBD. A case-control study by Kelsey et al. (1984) included a population of 232 subjects (cases) from a hospital identified as individuals with a prolapsed lumbar disc. The control group was identical to the cases but with no injury to the back. This study had two major findings. First, disc prolapse was associated with work-related lifting without twisting the body for lifting objects of 25 lb. or more (OR = 3.8, 95% CI: 0.7-20.1). Second, the highest risk was observed for both lifting and twisting that were performed at the same time with straight knees (OR = 6.1, 95% CI: 1.3-27.9).

Hoogendoorn et al. (2000) performed a prospective cohort study that examined the association between torso flexion (≤ 30º, 30-60º, 60-90º) and rotation (≥ 30º) of the torso during lifting with OLBDs. Subjects were identified with OLBD if they reported on at least one out of three annual follow-up questionnaires that they had OLBD lasting for one day during the previous 12 months. The authors found an increase in the risk of reporting OLBD for workers who were exposed to 1) torso flexion (> 60˚) for more than 5% of the working time (RR = 1.5, 95% CI: 1.0-2.1), 2), torso rotation (> 30˚) for more than 10% of the working hours (RR = 1.3, 95% CI: 0.9-1.9), and 3) lifting a load of at least 25 kg more than 15 times during the working hours (RR = 1.6, 95% CI: 1.1-2.3) (Hoogendoorn et al., 2000).

2.2.4.3 Biomechanical Evidence of Twisting and OLBDs

Marras and Granata (1997) noticed a significant increase in both spinal load and spinal load variability during asymmetric lifting tasks. As a result, these efforts may exceed the biomechanical tolerances of the intervertebral disc and increase the risk of injury to the low back soft tissues (Marras & Granata, 1997). According to Marras and Mirka (1992), the need of torso muscle co-contractions increases during asymmetric low-back activity and results in increasing the compressive pressure on the lumbar spine.

2.3 OLBDs Risk and Exposure Assessment Methods

In order to design low risk MMH jobs or evaluate MMH jobs to determine the level of risk for OLBD, assessment methods or procedures are needed. Many assessment methods have been developed over the past three decades, of which commonly used ones are briefly described below (Table 2.1).

TABLE 2.1

INPUT PARAMETERS AND OUTCOMES OF FIVE LIFTING ASSESSMENT TOOLS

Input variables	NIOSH	WA L&I	Snook	Ohio BWC Lifting Guidelines	ACGIH TLV
Anthropometry		Yes	Yes	Yes	Yes
Maximum lift (kg)	23	41	Subject based	32	32
Maximum Frequency (lift/min)	15	10	4	1	6
Duration	Yes	Yes			Yes
Origin (H&V)	Yes	Yes	Yes	Yes	Yes
Destination (H&V)	Yes				
Load Travel distance	Yes		Yes		
Coupling	Yes				
Maximum TorsoAsymmetry	135˚	45˚	0˚	90˚	30˚
Outcomes	Recommended weight limit; lifting index	Lifting limit	Percent Capable	-Weight limit -Risk determination (High, medium, low)	Threshhold Limit Value

- *The Revised 1991 National Institute of Occupational Safety and Health (NIOSH) Lifting Equation*

  This method utilizes task characteristics (i.e. lift frequency, duration, horizontal and vertical location of the load, torso asymmetry, coupling, and vertical travel distance of the load) to determine a recommended weight limit (RWL) that reduces the risk of low back injury. The actual load weight that is lifted is then divided by the RWL to determine the lifting index (LI) which reflects the relative risk of different lifting tasks. NIOSH indicates that LI's ≤ 1.0 are considered low-risk, LI's between 1.0 and 3.0 are moderate risk, and LI's ≥ 3.0 are high risk for OLBD (Russell, Winnemuller, Camp, & Johnson, 2007). This method is one of the most validated lifting assessment methods (Hidalgo et al. 1995; Waters et al. 1999; Marras, Fine, Ferguson, & Waters, 1999), and even is considered to be the best in evaluating the lifting jobs; however, it has some limitations. This method cannot be used in cases such as one-handed lifts, duration of lifting more than 8 hours, seated or kneeling lifting, and/or carrying/pushing/pulling tasks.

- *The Washington State Ergonomics Rule Lifting Calculator (WA L&I)*

  The Washington State Ergonomics Rule Lifting Calculator is part of an overall checklist designed to identify the risk of musculoskeletal disorders in the workplace, which assesses factors such as awkward postures, highly repetitive motions, high hand force, repeated impacts, lifting, and hand/arm vibration. Two sets of checklists are used: a Caution Zone checklist and a Hazard Zone checklist. This method includes the factors such as; the lift frequency and duration, load weight, torso asymmetry (i.e. 0 up to 45 degrees), and horizontal and vertical locations of the lift origin. This method and the weight limits were developed based largely on the NIOSH Lifting Equation. However, the weight limits developed are consistent with a NIOSH Lifting Index of 2.0 (Russell et al., 2007), which represents moderate risk for OLBD, not low risk.

- *The Liberty Mutual ‘‘Snook’’ Lifting Tables*

This method applies to more varied tasks (i.e. lifting, lowering, pushing, pulling, and carrying) than the Revised NIOSH Lifting Equation and other lifting assessment methods. This method provides a percent of workers who are capable of lifts and lowers, with different task characteristics. This assessment method includes the horizontal and vertical locations of the lift origin, frequency, gender, and percentage of the capable population as musculoskeletal disorder risk factors (Russell et al., 2007). This assessment method has been widely used (Dempsey & Maynard, 2005). However, this method only assesses jobs with sagittally symmetric torso postures, which are very rare in the workplaces where more than 85% of the lifting jobs require asymmetric torso postures (Dempsey, 2003).

- *Ohio Bureau of Workers' Compensation (BWC) Lifting Guidelines*

This assessment method provides guidance for identifying low risk lifting conditions for workers returning to work with LBP. It includes tables for lifting tasks with three different ranges of torso asymmetry (i.e. 0˚-30˚, 30˚-60˚, and 60˚-90˚) at the lift origin. These guidelines are for workers with LBP as well as asymptomatic workers. This method includes factors such as; the worker's health, load weight, horizontal reach distance from the spine, and vertical lift origin from the floor (Ferguson et al., 2005). The major limitation of the Ohio BWC Lifting Guidelines is that it only applies to lifting tasks with a frequency rate of one lift per minute or less.

- *The American Conference of Governmental Industrial Hygienists (ACGIH) Threshold Limit Values (TLV) for Lifting*

This method includes three set of tables (Tables 2.2-2.4) that are used to recommend lifting weights known as threshold limit values (TLV's). The three tables include lifting zones that are the combination of different horizontal distances of the load from the ankles (i.e. <30, >30-60, and >60-80cm) and different vertical height of the load from the floor (i.e. floor-mid shin, mid shin-knuckle, knuckle-shoulder, and reach limit above shoulder). Each table represents different lifting frequency and duration. This assessment method assesses exposure factors such as; exposure duration (less or more than 2 hours/day), lifting frequency (number of lifts/hr.), horizontal reach distance that the worker extends his/her arm to, vertical reach height for the arm elevation (Figure 2.1), torso asymmetry degree (i.e. 0-30 degrees), and the load weight. Based on the assessment of the exposure factors, specific lifting weights are recommended as TLV's. These TLV's are believed to be weights that almost all workers who perform two-handed lifting activities, in front of his/her body, and in an erect position can lift repetitively without developing OLBD problems (ACGIH, 2007).

There are a number of advantages for this method. It is an easy and quick method to use, for it only requires the identification of the above described exposure factors. As a result, it can provide quick solution strategies to the existing problem. Additionally, it enables for redesigning the studied job to change from a high risk category to low risk one (Amick, Zarzar, Jorgensen, 2011).

There are a number of drawbacks in the five previously described lifting assessment methods. For instance, even though the NIOSH Lifting Equation is the most validated method, it is not a straightforward method to use, especially navigating and solving some of the equations.

The Washington State Ergonomics Rule Lifting method provides lifting limits that represent the medium risk of OLBD (i.e. equivalent to the LI of 2.0 in the NIOSH Lifting Equation), but not a low risk. The Liberty Mutual "Snook" Lifting method assess symmetric lifting tasks, only. The Ohio BWC Lifting Guidelines method is not applicable for lifting tasks with more than one lift per minute. Finally, the ACGIH TLV assessment method assesses lifting tasks with torso asymmetry from 0 to 30 degrees, however, this method is an easy to use assessment method and assesses lifting tasks with lifting frequency rate up to 360 lifts per hour.

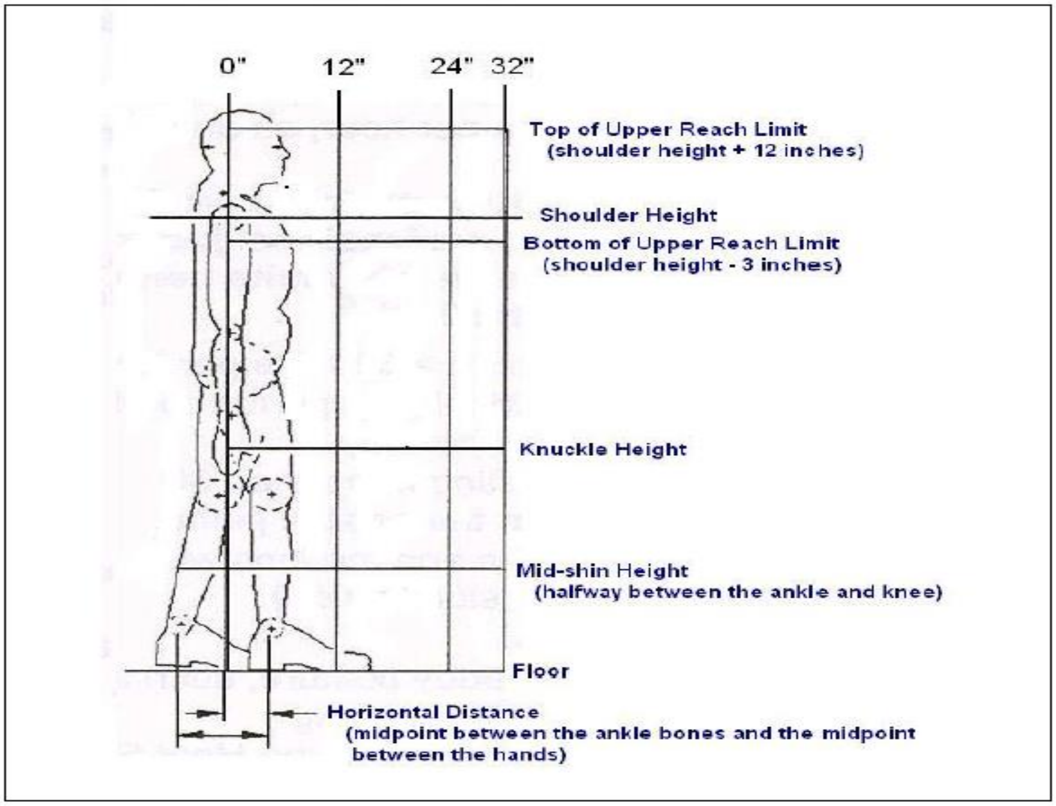
2.4 Voids and Unknowns

Dempsey (2003) estimated that more than 25% of occupational lifts had torso asymmetry greater than 30 degrees. However, the ACGIH TLV only addresses lifting and lowering tasks torso asymmetry between zero and 30 degrees. Thus, there is a void in the research literature and the utilization of the ACGIH TLV for Lifting assessment method for tasks that have torso asymmetry greater than 30 degrees.

2.5 Research Objectives

The research objectives of this study are:

- Determine the OLBD risk levels for ACGIH TLV's at torso asymmetry between 0 and 30 degrees from selected lifting zones.
- Determine the OLBD risk levels for lifting with torso asymmetry greater than 30 degrees using the TLV's for 0 to 30 degrees torso asymmetry.
- If needed, determine adjusted TLV's for lifting tasks with OLBD risk level more than 30% (i.e. moderate risk) for lifting with torso asymmetry from 0 to 90 degrees.



Adapted from ACGIH (2007)
Figure 2.1. Illustration of hand location (vertically and horizontally)

TABLE 2.2

ACGIH TLV TABLE FOR LOW REPETITIVE Jobs THAT ARE ≤ 2 HOURS PER DAY WITH ≤ 60 LIFTS PER HOUR OR ≥ 2 HOURS PER Day WITH ≤ 12 LIFTS PER HOUR

Vertical Height of Hands	Horizontal Distance of Hands from Body *A*		
	Close: < 12 inches (<30 cm)	Intermediate: 12-24 inches (30-60 cm)	Extended:*B* >25-32 inches (>60-80 cm)
Reach Limit:*C*	35 lbs (16 kg)	15 lbs (7 kg)	No known safe limit for repetitive lifting *D*
Shoulder Area: 12” (30 cm) above to 3” (7.5 cm) below shoulder	35 lbs (16 kg)	15 lbs (7 kg)	No known safe limit for repetitive lifting *D*
Torso Area: Below shoulder to knuckle height *E*	70 lbs (32 kg)	35 lbs (16 kg)	20 lbs (9 kg)
Knee Area: Knuckle to middle of shin height *E*	40 lbs (18 kg)	30 lbs (14 kg)	15 lbs (7 kg)
Ankle Area: Middle of shin height to floor	30 lbs (14 kg)	No known safe limit for repetitive lifting *D*	No known safe limit for repetitive lifting *D*

Footnotes for Table 2.2:
A. Distance from midpoint between inner ankle bones and the load
B. Lifting tasks should not start or end at the horizontal reach distance more then 32 inches (80 cm) from the midpoint between the inner ankle bones (See Figure 6)
C. Routine lifting tasks should not start or end at heights that are greater than 12 inches (30 cm) above the shoulder or more than 71 inches (178 cm) above floor level (see Figure 2.1)
D. Routine lifting tasks should not be performed for shaded table entries marked “No known safe limit for repetitive lifting.” While the available evidence does not permit identification of safe weight limits in the shaded regions, professional judgment may be used to determine if infrequently lifts of light weight may be safe.
E. Anatomical landmark for knuckle height assumes the worker is standing erect with arms hanging at the sides.

TABLE 2.3

ACGIH TLV TABLE FOR MODERATE REPETITIVE JOBS THAT ARE > 2 HOURS PER DAY WITH > 12 AND ≤ 30 LIFTS PER HOUR OR≤ 2 HOURS PER DAY WITH > 60 AND ≤ 360 LIFTS PER HOUR

Vertical Height of Hands	Horizontal Distance of Hands from Body A		
	Close: < 12 inches (<30 cm)	Intermediate: 12-24 inches (30-60 cm)	Extended: B >25-32 inches (>60-80 cm)
Reach Limit: C	30 lbs (14 kg)	10 lbs (5 kg)	No known safe limit for repetitive lifting D
Shoulder Area: 12" (30 cm) above to 3" (7.5 cm) below shoulder	30 lbs (14 kg)	10 lbs (5 kg)	No known safe limit for repetitive lifting D
Torso Area: Below shoulder to knuckle height E	60 lbs (27 kg)	30 lbs (14 kg)	15 lbs (7 kg)
Knee Area: Knuckle to middle of shin height E	35 lbs (16 kg)	25 lbs (11 kg)	10 lbs (5 kg)
Ankle Area: Middle of shin height to floor	20 lbs (9 kg)	No known safe limit for repetitive lifting D	No known safe limit for repetitive lifting D

Footnotes for Table 2.3:
A. Distance from midpoint between inner ankle bones and the load
B. Lifting tasks should not start or end at the horizontal reach distance more then 32 inches (80 cm) from the midpoint between the inner ankle bones (See Figure 6)
C. Routine lifting tasks should not start or end at heights that are greater than 12 inches (30 cm) above the shoulder or more than 71 inches (178 cm) above floor level (see Figure 2.1)
D. Routine lifting tasks should not be performed for shaded table entries marked "No known safe limit for repetitive lifting." While the available evidence does not permit identification of safe weight limits in the shaded regions, professional judgment may be used to determine if infrequently lifts of light weight may be safe.
E. Anatomical landmark for knuckle height assumes the worker is standing erect with arms hanging at the sides.

TABLE 2.4

ACGIH TLV TABLE FOR HIGHLY REPETITIVE JOBS THAT ARE > 2 HOURS PER DAY WITH > 30and ≤ 360 LIFTS PER HOUR

Vertical Height of Hands	Horizontal Distance of Hands from Body A		
	Close: < 12 inches (<30 cm)	Intermediate: 12-24 inches (30-60 cm)	Extended:B >25-32 inches (>60-80 cm)
Reach Limit:C	25 lbs (11 kg)	No known safe limit for repetitive lifting D	No known safe limit for repetitive lifting D
Shoulder Area: 12" (30 cm) above to 3" (7.5 cm) below shoulder	25 lbs (11 kg)	No known safe limit for repetitive lifting D	No known safe limit for repetitive lifting D
Torso Area: Below shoulder to knuckle height E	30 lbs (14 kg)	20 lbs (9 kg)	10 lbs (5 kg)
Knee Area: Knuckle to middle of shin height E	20 lbs (9 kg)	15 lbs (7 kg)	5 lbs (2 kg)
Ankle Area: Middle of shin height to floor	No known safe limit for repetitive lifting D	No known safe limit for repetitive lifting D	No known safe limit for repetitive lifting D

Footnotes for Table 2.4:
A. Distance from midpoint between inner ankle bones and the load
B. Lifting tasks should not start or end at the horizontal reach distance more then 32 inches (80 cm) from the midpoint between the inner ankle bones (See Figure 6)
C. Routine lifting tasks should not start or end at heights that are greater than 12 inches (30 cm) above the shoulder or more than 71 inches (178 cm) above floor level (see Figure 2.1)
D. Routine lifting tasks should not be performed for shaded table entries marked "No known safe limit for repetitive lifting." While the available evidence does not permit identification of safe weight limits in the shaded regions, professional judgment may be used to determine if infrequently lifts of light weight may be safe.
E. Anatomical landmark for knuckle height assumes the worker is standing erect with arms hanging at the sides.

CHAPTER 3

METHODS

3.1 Approach

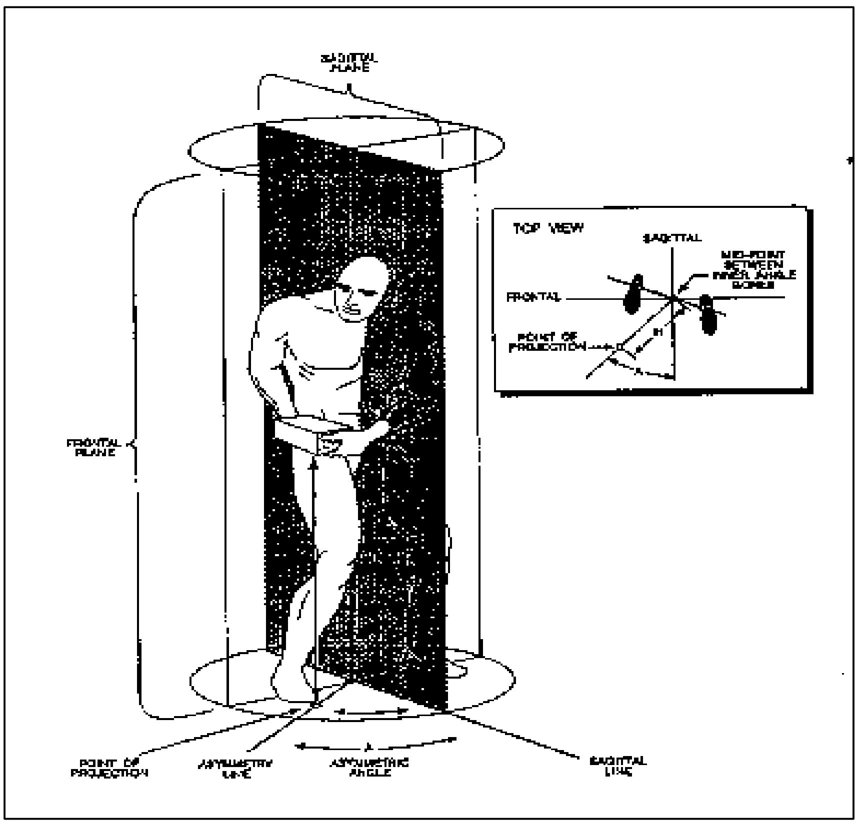
This study examined movements of the participants' torso in three planes of motion (i.e. coronal, sagittal, and transverse) while lifting different weights in a container from four different vertical and horizontal locations and seven different torso asymmetry angles. These locations corresponded to the ACGIH TLV's third table (Table 2.4) of prolonged and more frequent lifting tasks (more than two hours per day with lifting frequency between 30 and 360 lifts per hour). Data were collected using the Lumbar Motion Monitor (LMM) electrogoniometer and were interpreted using the Ohio State University (OSU) OLBD Risk Model (Marras et al., 1993). The study was approved by the Wichita State University Institutional Review Board for Human Subjects Research.

3.2 Participants

This study included twenty males between the age of 19 and 30 years who were free from any sort of previous LBP within the past six months. The mean age of the participants was 25.8 years old (SD=2.7). The average participants' weight was 77.2 kg (SD=16.5), and the mean stature was 172.1 cm (SD=4.5).

3.3 Study design

A height-adjustable table (the origin of the lift) was adjusted to two vertical and two horizontal lifting locations and located at seven different torso asymmetry angles (0, 15, 30, 45, 60, 75, and 90 degrees) away from the sagittal plane. According to Waters, Putz-Anderson, and Garg (1994), torso asymmetry liftings are those that begin or end outside the mid-sagittal plane as shown in Figure 3.1. The two vertical heights at the lift origin were a) knuckle to shoulder zone, which was adjusted to each participant's elbow height and b) mid-shin to knuckle zone, which was adjusted to each participant's knee height. The range of the horizontal distance in the ACGIH TLV's tables for the intermediate and far horizontal zones was from 30cm to 60cm and 60cm to 80cm, respectively. Amick et al. (2011) found that there was no significant difference in the OLBD Risk while lifting from different distances within the same horizontal zone. Therefore, the selected horizontal distances between the participant's inner ankle bones to the middle point between the hands at the origin of the lift were 50 cm to represent the intermediate horizontal zone and 70 cm to represent the extended horizontal zone.



Adapted from Waters et al., 1994

Figure 3.1. Torso asymmetry

A height-adjustable platform was used for the lifting task destination. The destination location was fixed in front of the participant, where the container handle was set at each participants' waist height.

The vertical and horizontal origin locations resulted in four lifting zones with different recommended weights (TLV's) for each zone. The first zone was knuckle to shoulder, intermediate with a TLV of 9 kg. The second zone was knuckle to shoulder, extended, with a TLV of 5 kg. The third zone was mid-shin to knuckle, intermediate with a TLV of 7 kg. The fourth zone was mid-shin to knuckle, extended zone with a TLV of 2 kg. The various zones and associated TLV's are shown in Table 3.1. The lifting conditions (i.e. frequency and duration) in the ACGIH third table applies in many industrial workplaces, in which workers who are involved in manual material handling jobs lift more frequently (30< lifts per hour<360) for more than 2 hours per day. In a study that included assessment of more than one thousand jobs in the milk manufacturing industry, Dempsey (2003) found that workers performed a mean of 60 lifts per hour. Therefore, this table was utilized in this study to examine the appropriateness of the TLV's at torso asymmetry angles greater than 30 degrees.

TABLE 3.1

THE SELECTED ZONES AND TLV's FROM ACGIH TLV's TABLE FOR THE HIGHLY REPETITIVE JOB

Vertical Height of Hands	Horizontal Distance of Hands from Body A		
	Close: < 12 inches (30 cm)	Intermediate: 12-24 inches (30-60 cm)	Extended: B 25-32 inches (60-80 cm)
Reach Limit: C	25 lbs (11 kg)	No known safe limit for repetitive lifting D	No known safe limit for repetitive lifting D
Shoulder Area: 12" (30 cm) above to 3" (7.5 cm) below shoulder	25 lbs (11 kg)	No known safe limit for repetitive lifting D	No known safe limit for repetitive lifting D
Torso Area: Below shoulder to knuckle height E	30 lbs (14 kg)	20 lbs (9 kg)	10 lbs (5 kg)
Knee Area: Knuckle to middle of shin height E	20 lbs (9 kg)	15 lbs (7 kg)	5 lbs (2 kg)

3.4 Experimental Design

The experimental design consisted of a repeated measures three-factor design, where all participants were exposed to all levels of all three factors. The independent variables consisted of the vertical zone (mid-shin to knuckle, and knuckle to shoulder), the horizontal zone (intermediate and extended), and torso asymmetry (0, 15, 30, 45, 60, 75, and 90 degrees). The dependent variable consisted of the output of the OLBD Risk model's probability of high risk group membership (i.e. OLBD Risk).

3.5 Experimental Procedures

Upon arrival of each participant to the lab, the study procedures were explained. Participants were asked to read and sign the approved consent form. Demographics (age) and anthropometry data were then collected. Anthropometry consisted of stature, elbow height, waist height, knee height, and body mass. The participants were then fitted with the LMM (see Figure 3.2), which is an exoskeleton of the spine used to quantify the torso kinematics. The LMM was attached to the participants' torso by a waist harness and a chest harness.

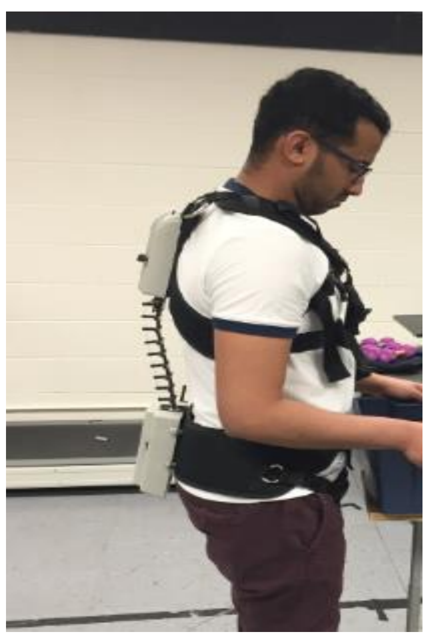


Figure 3.2. A participant fitted with LMM

The participants lifted a container (40.1 x 26.2 x 17.8 cm) from different lifting zones (i.e. knuckle to shoulder height-intermediate distance, knuckle to shoulder height-extended distance, mid-shin to knuckle height-intermediate distance, and mid-shin to knuckle height-extended distance) to a common destination. Lifting from each zone was repeated at different torso asymmetry angles (i.e. 0, 15, 30, 45, 60, 75, and 90 degrees). Figures 3.3 through 3.8 demonstrate some of the various lifting zones. The container weight was adjusted with different metal weights (i.e. 2, 5, 7, and 9 kg), to correspond to the TLV for the specific zone lifted from. The order of the lifting tasks was randomized for each participant. A line was drawn on the floor to specify the specific torso asymmetry angles and horizontal distances for each lifting condition. The participants were asked to keep their feet fixed on that line during all the lifting tasks. During the lifting tasks, an investigator measured the horizontal distance between the approximate participant's L5/S1 intervertebral disc location and the hand-coupling (third metacarpal-phalangeal joint) of the container to quantify the horizontal external load moment arm using a tape measure. The value was combined with the container weight (i.e. TLV) to determine the external load moment for each lift. The lift rate was controlled using an automatic alarm generator that generated a tone every 15 seconds for a lift rate of four lifts per minute (i.e. 240 lifts per hour), where the participant was instructed to start the lift each time the tone sounded. For each lifting condition (i.e. vertical zone, horizontal zone, and torso asymmetry combination) the participant performed four replications. The lifted container was returned from the destination platform to the lift origin by the researcher at the end of each transfer by the participant.

3.6 Data analysis

The torso kinematics data, moment arm, and load weight were input into the software utilized with the LMM (BALLET^{TM} 2.0), which then determined the probability of high risk group membership, for each vertical zone, horizontal zone, and torso asymmetry condition, for each participant.

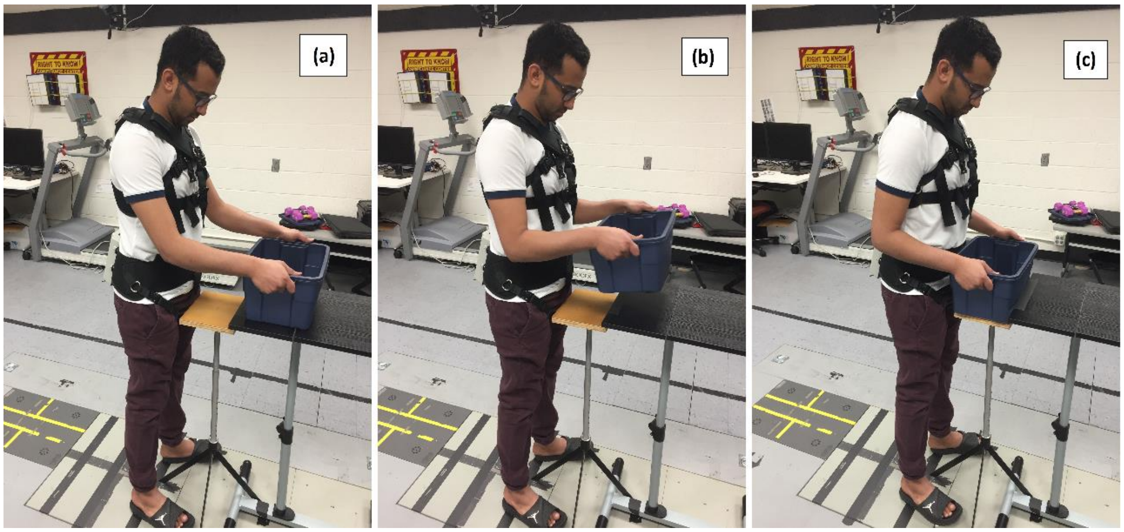


Figure 3.3. Knuckle to shoulder- intermediate zone at 0 degree of torso asymmetry
(a) origin, (b) midpoint, and (c) destination

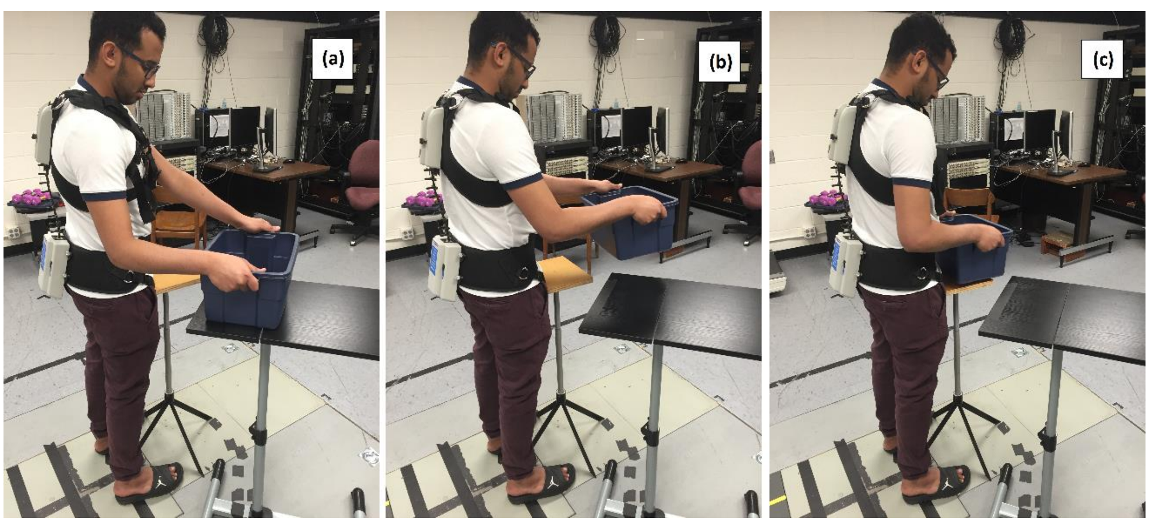


Figure 3.4. Knuckle to shoulder- intermediate zone at 60 degrees of torso asymmetry
(a) origin, (b) midpoint, and (c) destination

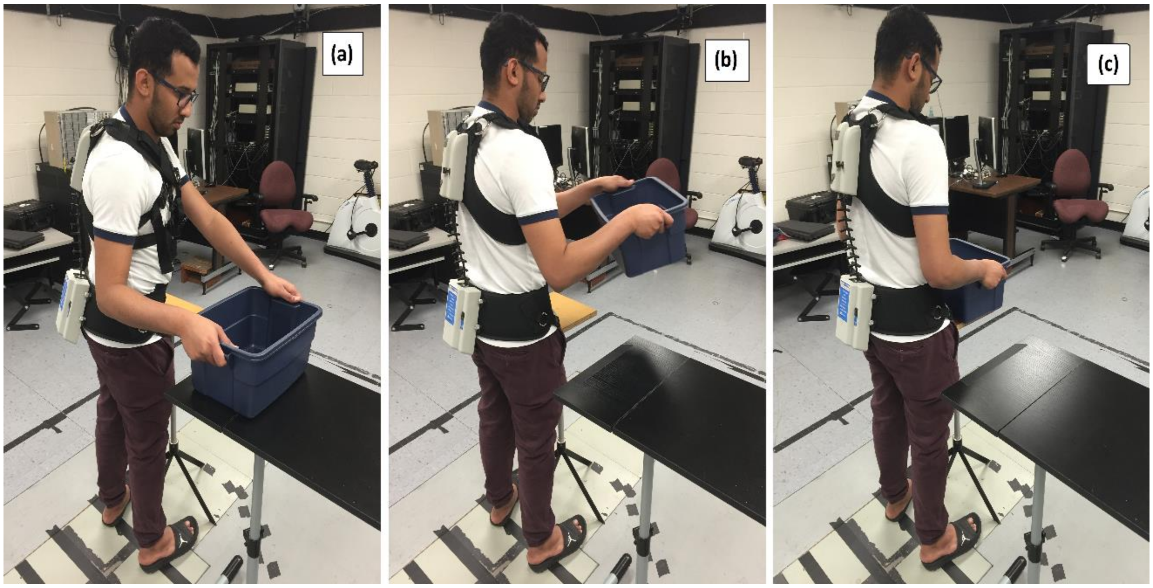


Figure 3.5. Knuckle to shoulder- intermediate zone at 90 degrees of torso asymmetry
(a) origin, (b) midpoint, and (c) destination

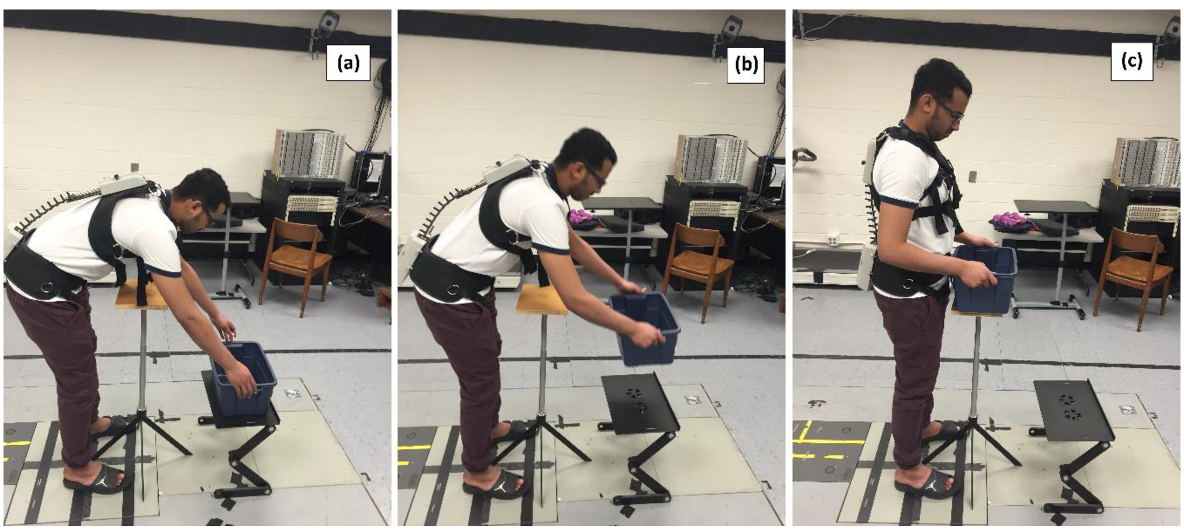


Figure 3.6. Mid-shin to knuckle- extended zone at 0 degree of torso asymmetry
(a) origin, (b) midpoint, and (c) destination

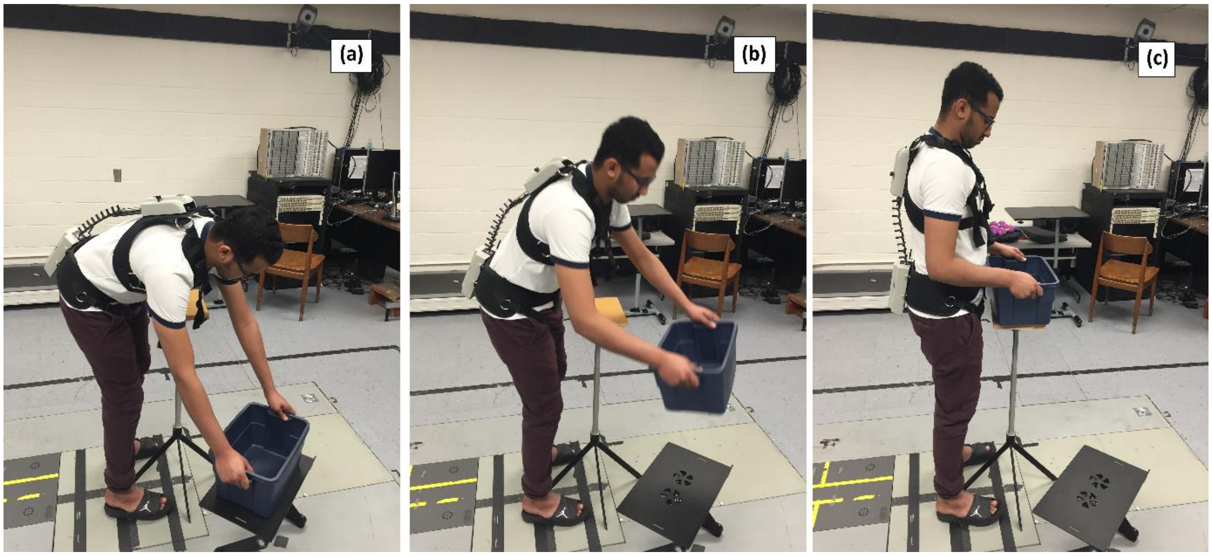


Figure 3.7. Mid-shin to knuckle-extended zone at 60 degrees of torso asymmetry
(a) origin, (b) midpoint, and (c) destination

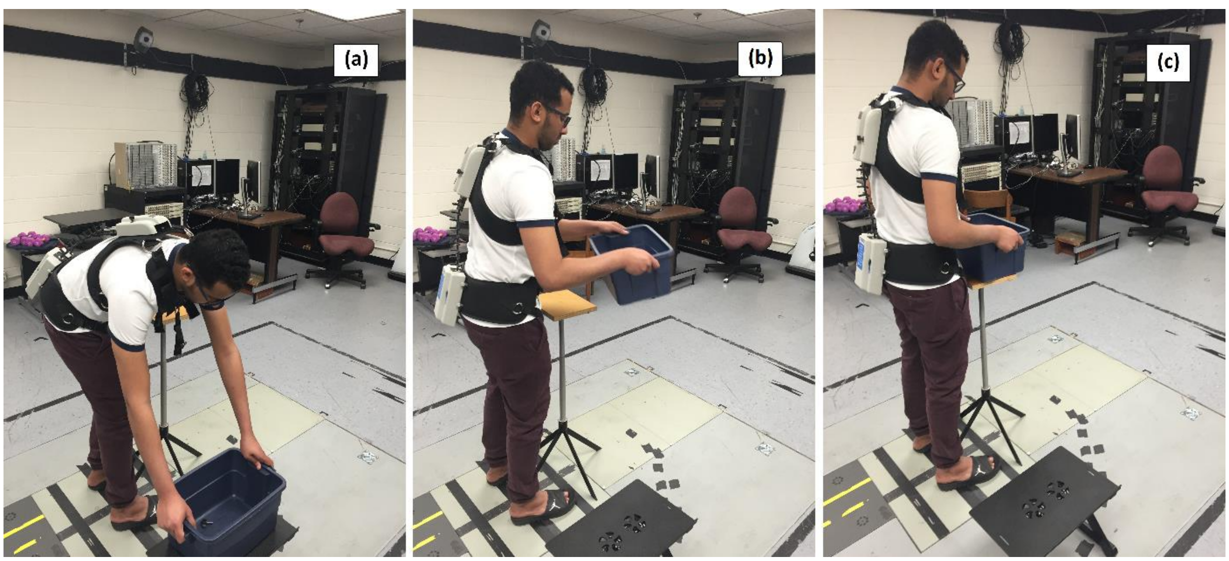


Figure 3.8. Mid-shin to knuckle- extended zone at 90 degrees of torso asymmetry
(a) origin, (b) midpoint, and (c) destination

3.7 Statistical Analysis

Descriptive statistics (means and standard deviations (SD)) were tabulated for OLBD Risk (as a function of vertical zone, horizontal zone, and torso asymmetry) as well as the participants' demographics and anthropometric data. Statgraphics statistical analysis software (version XVII -

X64, Warrenton, VA) was utilized to perform the statistical analysis on the resulting OLBD Risk probabilities. A three-way Analysis of Variance (ANOVA) was performed to study the impact of the independent variables (vertical zone, horizontal zone, and torso asymmetry) on the OLBD Risk probability. Significant main effects ($p \leq 0.05$) and two-way interactions ($p \leq 0.05$) were investigated by a Tukey HSD post-hoc test.

A multiple linear regression analysis was performed to first develop a prediction equation for the OLBD Risk based on the various identified variables, and second, to determine the TLV's by setting OLBD Risk at specific probability values so can be lifted with low risk for OLBD. First, the OLBD Risk probability was set as the dependent variable, and the vertical zone, horizontal zone, TLV weight, and torso asymmetry degree were the independent variables. A dummy function was created to represent the different levels of vertical and horizontal zones, in which the value of 1 denotes knuckle to shoulder zone (vertically) and extended distance (horizontally). Similarly, the value of 0 denotes mid-shin to knuckle zone (vertically) and intermediate distance (horizontally). Second, once the OLBD Risk prediction equation was determined, the OLBD Risk probability value was fixed at 30% (i.e. low risk for OLBD) and the equation was solved to find an adjusted TLV if necessary.

CHAPTER 4

RESULTS

After recording the torso motion factors (using the LMM) and measuring the external load moment arm for each participant, the moment arm readings along with the load weight were input into the software (BALLET^{TM} 2.0) to determine the OLBD Risk probability for each participant. For example, Figure 4.1 shows the OLBD risk probability for Knuckle to Shoulder, Extended zone that involves 0˚ torso twisting. The probability value for this task was 23%, which is the probability of classifying this job within the high risk OLBD group. The average of each OLBD Risk model input variable percentage are then averaged to determine the task high risk OLBD group membership probability ((71% + 4% + 25% + 16% + 1%)/5 = 23.4 ≈23%).

Descriptive statistics (i.e. mean and standard deviation (SD)) for OLBD Risk probability by vertical height, horizontal zone, and torso asymmetry are shown in Table 4.1. Additionally, these data are also shown in Figures 4.2 through 4.5. For each of the lifting zone combinations shown in these figures, the OLBD Risk increased gradually when moving from 0˚ torso asymmetry to 90˚ torso asymmetry away from the sagittal plane. It can be noticed from these figures that lifting tasks that were performed in the knuckle to shoulder zone (Figure 4.2 and 4.3) at the two horizontal distances with torso asymmetry of 0 and 15 degrees resulted in OLBD Risk probability values that were less than 30%, which represents the low risk category. Additionally, lifting tasks with torso asymmetry of 30 degrees were slightly above the OLBD threshold Risk of 30% in the knuckle to shoulder extended (33%) and intermediate (35%) zones. In the mid-shin to knuckle zone, however, all lifting tasks of torso asymmetry within 30 degrees (i.e. 0, 15, and 30 degrees) at both horizontal distances were in the moderate risk category (i.e. 30% < OLBD Risk probability < 70%; Marras, Allread, Burr, & Fathallah, 2000). Finally, Figures 4.2 through 4.5 illustrated that in the four lifting zones, the OLBD Risk probability for lifting tasks that involved torso asymmetry greater than 30 degrees were in the moderate risk category.

TABLE 4.1

MEAN (SD) OLBD RISK PROBABILITY FOR EACH LIFTING CONDITION

Lifting Zone	TLV Weight (kg)	Asymmetry (Deg)	MEAN (SD) OLBD Risk (%)
Knuckle to Shoulder-Extended	5	0	23 (5.0)
		15	28 (5.3)
		30	33 (6.2)
		45	36 (7.2)
		60	41 (6.8)
		75	48 (6.5)
		90	50 (6.2)
Knuckle to Shoulder-Intermediate	9	0	25 (3.1)
		15	30 (4.4)
		30	35 (4.0)
		45	39 (5.6)
		60	41 (4.9)
		75	44 (4.4)
		90	49 (6.3)
Mid-Shin to Knuckle-Extended	2	0	36 (2.6)
		15	37 (2.3)
		30	40 (3.7)
		45	43 (4.1)
		60	43 (4.0)
		75	46 (4.2)
		90	48 (4.4)
Mid-Shin to Knuckle-Intermediate	7	0	42 (1.4)
		15	45 (4.1)
		30	47 (3.7)
		45	50 (4.8)
		60	51 (4.8)
		75	51 (4.1)
		90	54 (6.7)

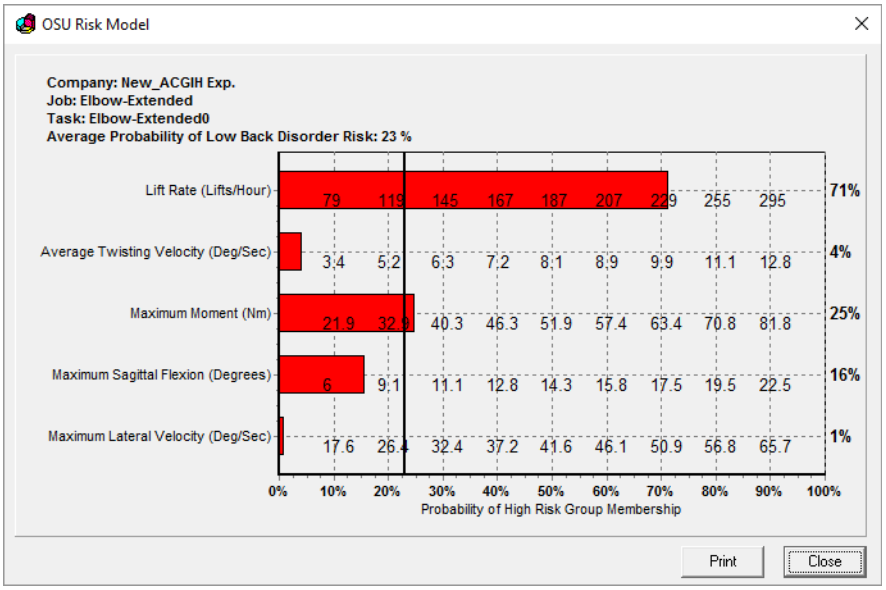


Figure 4.1. Probability of high risk group membership for knuckle to shoulder, extended-0 degree torso asymmetry task

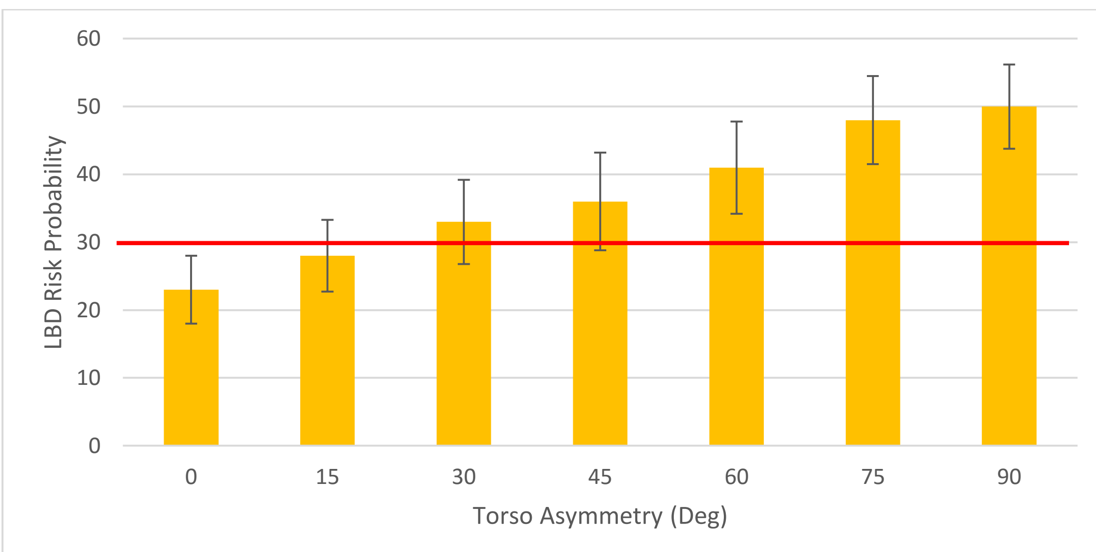


Figure 4.2. OLBD Risk for knuckle to shoulder, extended zone, as a function of torso asymmetry. Error bars represent +/- 1 standard deviation

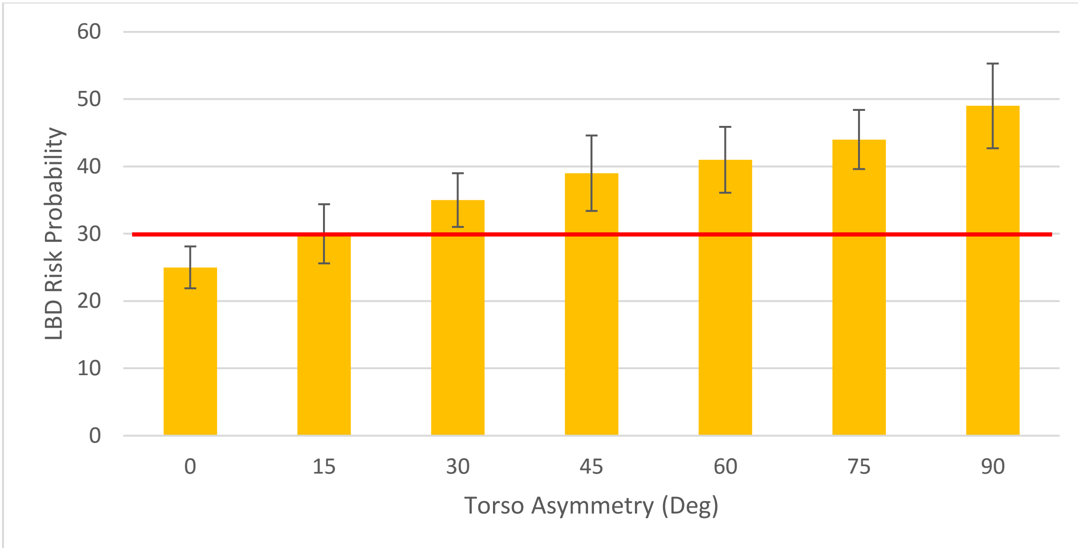


Figure 4.3. OLBD Risk for knuckle to shoulder, intermediate zone, as a function of torso asymmetry. Error bars represent +/- 1 standard deviation

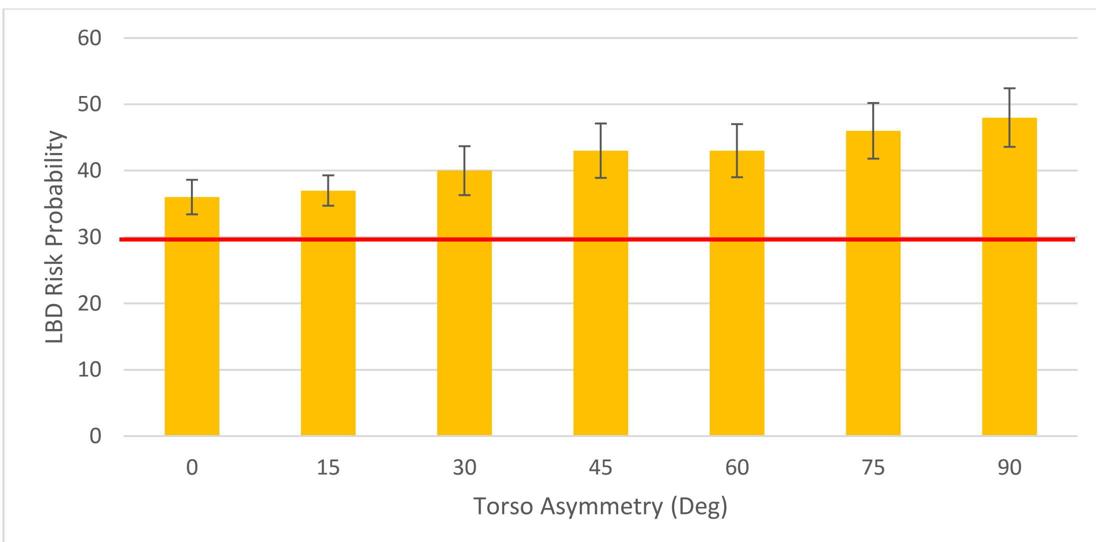


Figure 4.4. OLBD Risk for mid-shin to knuckle, extended zone, as a function of torso asymmetry. Error bars represent +/- 1 standard deviation

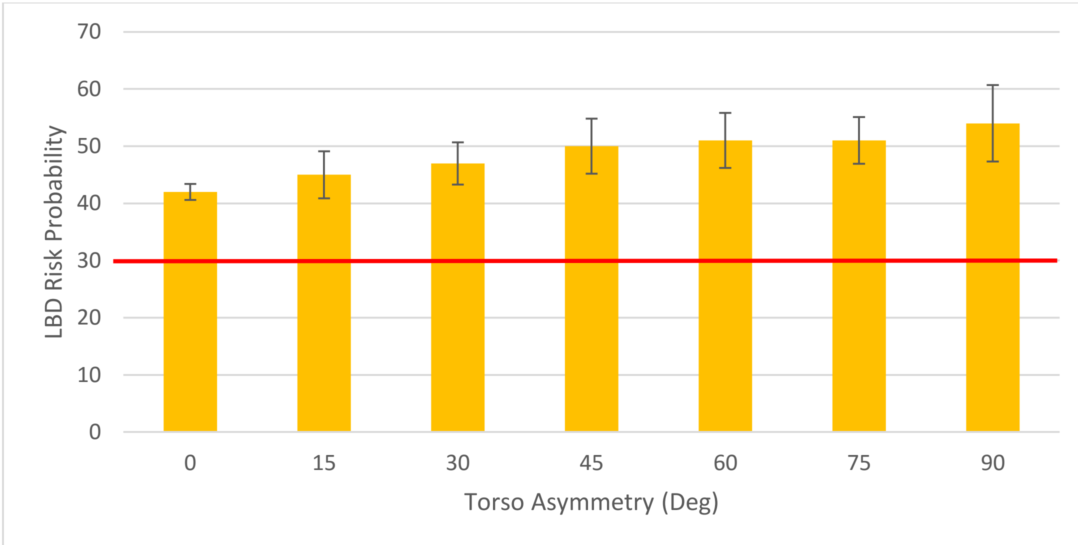


Figure 4.5. OLBD Risk for mid-shin to knuckle, intermediate zone, as a function of torso asymmetry. Error bars represent +/- 1 standard deviation

A three-way ANOVA was performed to assess the effect of the four independent variables upon the OLBD Risk probability. As shown in Table 4.2, the main effects of the vertical zone, horizontal zone, and torso asymmetry all had a significant affect on the OLBD Risk probability ($p \leq 0.0001$). The ANOVA also indicated two significant interactions. The OLBD Risk probability varied significantly as a function of the vertical zone and horizontal zone ($p = 0.0002$) as well as the vertical zone and torso asymmetry ($p = 0.0005$). However, the OLBD Risk probability did not vary significantly as a function horizontal zone and torso asymmetry ($p = 0.1199$).

Results of the follow-up Tukey HSD post hoc tests on the significant interactions are shown in Figure 4.6 and Figure 4.7. For the significant vertical by horizontal zone interaction (Figure 4.6), the OLBD Risk probability was significantly different between the knuckle to shoulder zone (37.6%) and mid-shin to knuckle zone (48.6%) only at the intermediate horizontal zone.

TABLE 4.2

MULTIFACTORIAL ANOVA FOR OLBD RISK PROBABILITY WITH VERTICAL, HORIZONTAL, AND TORSO ASYMMETRY

Source	*Sum of Squares*	*Df*	*Mean Square*	*F-Ratio*	*P-Value*
MAIN EFFECTS					
Vertical Zone	440.036	1	440.036	462.04	0.0000
Horizontal Zone	92.8929	1	92.8929	97.54	0.0001
Asymmetry	1062	6	177	185.85	0.0000
INTERACTIONS					
Vertical* Horizontal	66.0357	1	66.0357	69.34	0.0002
Vertical* Asymmetry	144.714	6	24.119	25.33	0.0005
Horizontal*Asymmetry	15.8571	6	2.64286	2.78	0.1199
RESIDUAL	5.71429	6	0.952381		
TOTAL (CORRECTED)	1827.25	27			

For the significant vertical zone by torso asymmetry interaction (Figure 4.7), the OLBD Risk probability was significantly different between the two vertical zones at torso asymmetry angles of 0, 15, 30, 45, and 60 degrees, but not for 75 and 90 degrees of torso asymmetry.

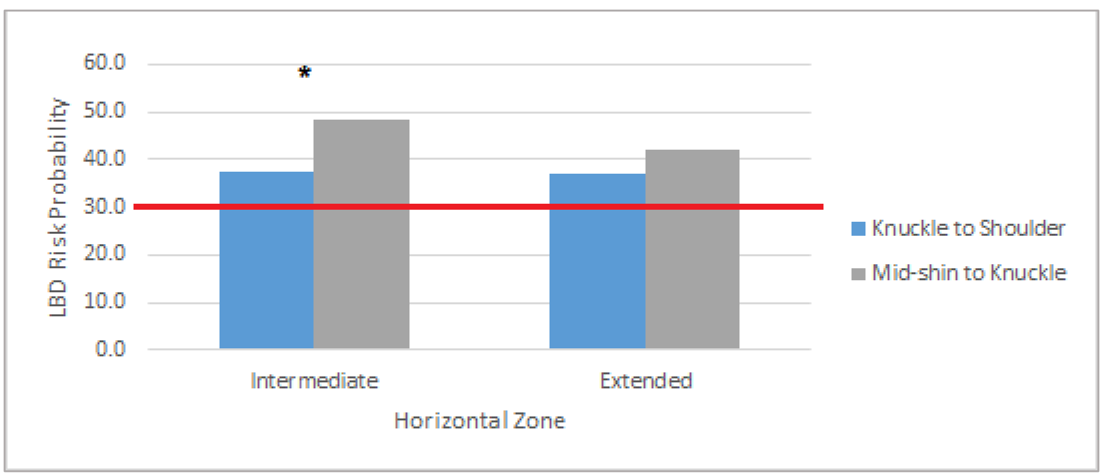


Figure 4.6. Mean OLBD Risk as a function of vertical height with respect to the horizontal distance
(* significantly different at $\alpha_F = 0.05$)

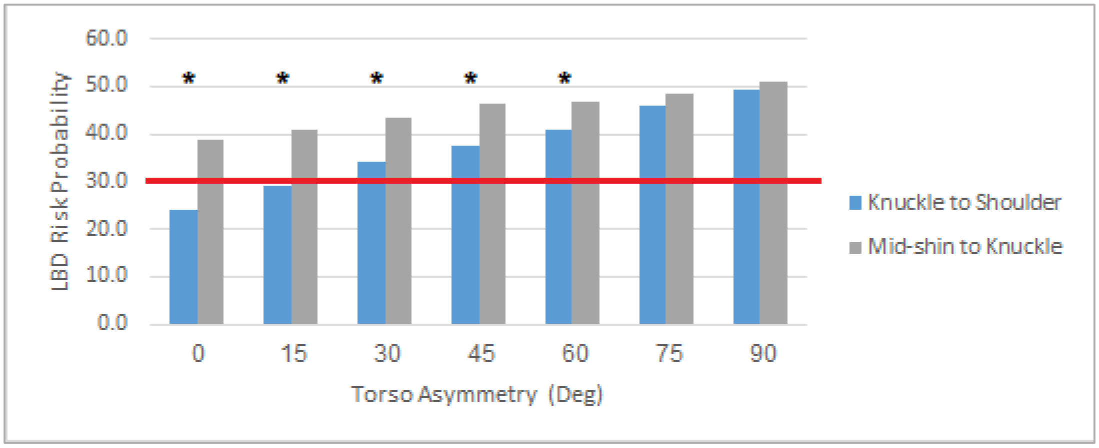


Figure 4.7. Mean OLBD Risk as a function of vertical height with respect to the torso asymmetry (* significantly different at $\alpha_F = 0.05$)

A multiple linear regression was performed to develop a relationship between the lifting zone categories, torso asymmetry, and TLV weight. As shown in Table 4.3, the model significantly predicts the OLBD Risk probability ($p < 0.0001$), with an adjusted R^2 of 0.8896. Additionally, as shown in Table 4.4, each of the independent variables was a significant predictor of the OLBD Risk probability value.

The resulting fitted equation (Equation 4.1) for the prediction of the OLBD Risk probability with respect to the other four independent variables is:

$$OLBD\ Risk\ (\%) = -3.64286 - 23.2857*Vertical\ H + 24.0*Horizontal\ D + 6.14286*TLVs\ (kg) + 0.204762*Torso\ Asymmetry\ (Deg.) \quad (4.1)$$

where,

Vertical H= the vertical zone, 0 for knuckle to shoulder height, 1 for mid-shin to knuckle height

Horizontal D= horizontal zone, 0 for extended distance, 1 for intermediate distance

Applying the obtained regression equation (Equation 4.1), new TLV's were suggested for all lifting tasks that resulted in moderate risk of OLBD. Moreover, the equation was utilized to predict the value of the load weight (TLV), in which the OLBD Risk probability value was set at the OLBD Risk probability value of 30%, that represents the low risk category (Marras et al., 2000). For instance, for the knuckle to shoulder-extended zone with torso asymmetry of 90˚, the OLBD Risk probability was set at 30% and the suggested TLV for this task was 2 kg instead of 5 kg (i.e. ACGIH TLV for knuckle to shoulder-extended zone with 0˚-30˚ torso asymmetry). This reduction in the TLV should reduce the OLBD Risk probability value from 50% to 30%. Other suggested adjusted TLV's are shown in Table 4.5. As can be noticed in this table, there are no safe TLV's suggested for lifting tasks in mid-shin to knuckle zone at the extended horizontal distance for lifting tasks that involved torso asymmetry greater than 30˚. This was determined after applying the OLBD prediction equation (i.e. Equation 4.1), where the obtained TLV's were less than or equal to the zero, which suggested no safe limit is recommended. Lower TLV's were suggested for lifting tasks in the mid-shin to knuckle with torso asymmetry within 30˚ (Table 4.5).

TABLE 4.3

MULTIPLE LINEAR REGRESSION MODEL-ANALYSIS OF VARIANCE (ANOVA)

Source	*Sum of Squares*	*Df*	*Mean Square*	*F-Ratio*	*P-Value*
Model	1655.54	4	413.884	55.44	0.00
Residual	171.714	23	7.46584		
Total (Corr.)	1827.25	27			

TABLE 4.4

MODEL INDPENDENT VARIABLES-PARAMETER ESTIMATES

Parameter	*Estimate*	*Standard Error*	*T Statistic*	*P-Value*
CONSTANT	-3.64	13.99	-0.26	0.80
Vertical Zone	-23.29	5.27	-4.42	0.00
Horizontal Zone	24.00	9.35	2.57	0.02
Load Weight (kg)	6.14	2.07	2.97	0.01
Asymmetry (Deg.)	0.20	0.02	11.90	0.00

TABLE 4.5

ADJUSTED TLV'S FOR MODERATE OLBD RISK ASYMMETRIC LIFTING TASKS

Vertical and Horizontal	Torso Asymmetry (Deg.)	ACGIH TLV's For 0-30 Deg. Torso Asymmetry (kg)	The Adjusted TLV's (kg)
Knuckle To Shoulder-Extended	0	5	5*
	15		5*
	30		5*
	45		4
	60		3
	75		3
	90		2
Knuckle To Shoulder-Intermediate	0	9	9*
	15		9*
	30		9*
	45		8
	60		7
	75		7
	90		6
Mid-Shin To Knuckle-Extended	0	2	2
	15		1
	30		1
	45		No Safe TLV
	60		No Safe TLV
	75		No Safe TLV
	90		No Safe TLV
Mid-Shin To Knuckle-Intermediate	0	7	5
	15		5
	30		4
	45		4
	60		3
	75		3
	90		2

* Not an adjusted TLV, this condition resulted in a low risk probability of high risk group membership (≤ 30%).

CHAPTER 5

DISCUSSION

5.1 The OLBD Risk Model

Marras et al. (2000) has categorized the OLBD Risk probability as low risk (i.e. ≤ 30%), moderate risk (i.e. > 30% and < 70%), and high risk (i.e. ≥ 70%). The adequacy of this OLBD Risk model was validated for its accuracy in defining the probability of high risk group membership for manual material handling activities, where a prospective study showed an association between the OLBD Risk level of the job and the expected number of OLBD incidence (Marras et al., 2000).

In the current study, it was observed that the greater the torso asymmetry angles, the higher the OLBD Risk probability. This finding concurs with Marras and Davis (1998) in which they have shown the more the torso asymmetry angle is involved, the higher the spinal loadings. Also, OLBD Risk probabilities were greater in the mid-shin to knuckle vertical zone in most of the lifting conditions. This finding is consistent with previous biomechanical studies (Marras and Sommerich, 1991b; Granta and Marras, 1993; 1995) and epidemiological studies (Punnett et al., 1991; Marras et al., 1993; Marras et al., 1995) that have shown that lifting below knuckle height is more hazardous than lifting from knuckle height to mid-chest height.

Based on the obtained OLBD Risk probabilities for the studied tasks no task was associated with more than 70% of OLBD risk, which means the studied tasks fell within the low risk (i.e. OLBD Risk probability ≤ 30%) and moderate risk (i.e. 30% < OLBD Risk probability < 70%) categories. Moreover, Figures 4.2-4.5 showed that lifting tasks with torso asymmetry greater than 30˚ in the four lifting zones were in the moderate risk category for OLBD. Lifting tasks with 30˚ torso asymmetry were slightly above the 30% threshold limit in the knuckle to shoulder zones in extended and intermediate horizontal zones (i.e. 33% and 35%, respectively), where the lifting tasks with 0˚ and 15˚ torso asymmetry were in the low risk category in these zones. However, lifting tasks of 0˚, 15˚ and 30˚ degrees were in the moderate risk category in the mid-shin to knuckle zone in the two horizontal zones.

5.2 Torso Asymmetry Less than or Equal To 30 Degrees

The findings of this study revealed that the suggested TLV's in the ACGIH TLV's table for the high frequency lifting jobs in the mid-shin to knuckle zone result in moderate risk of OLBD for lifting tasks with torso asymmetry within 30˚. To reduce the risk level from moderate to low in the mid-shin to knuckle-extended distance zone, the ACGIH TLV of 2 kg should be reduced to 1 kg for lifting with torso asymmetry of 15˚ and 30˚. Similarly, to reduce the risk level from moderate to low in the mid-shin to knuckle-intermediate distance zone, the ACGIH TLV of 7 kg should be reduced to 5, 5, and 4 kg for lifting with torso asymmetry of 0˚, 15˚ and 30˚, respectively (Table 4.6).

5.3 Torso Asymmetry Greater than 30 Degrees

The resulting OLBD Risk probability values suggest that there is a need for new recommended TLV's for lifting tasks with torso asymmetry greater than 30˚ (i.e. 45˚, 60˚, 75˚, and 90˚) in the four lifting zones to ensure the OLBD Risk values are within the low risk category. These TLV's were obtained after applying the multiple regression equation (Equation 4.1) which was developed to predict the OLBD Risk as a function of vertical height, horizontal distance, TLV, and torso asymmetry angle. The equation was solved to predict the TLV for each lifting task with an OLBD Risk probability value greater than 30% (i.e. moderate risk). Since the aim of this study was to recommend TLV's with low risk probability, the OLBD Risk value in the equation was maintained at 30%. For instance, Table 4.6 shows the ACGIH TLV for the lifting tasks that were performed in the mid-shin to knuckle-intermediate zone with lifting load (i.e. TLV) of 7 kg. Lifting this TLV in this lifting zone with torso asymmetry of 90˚ resulted in OLBD Risk probability value of 54%, which lies in the moderate risk category. However, the suggested TLV for this particular lifting task was 2 kg to diminish the risk from moderate to low (i.e. 30%). Other new recommended TLV's are tabulated in Table 4.6. Also, it can be noticed in this table that there are no low risk TLV's in the mid-shin to knuckle-extended zone for lifting that involves torso asymmetry greater than 30˚, which suggests workers are strongly advised to avoid lifting any weight in these lifting conditions, or the task and work area should be redesigned to reduce the risk of OLBD.

5.4 The Correlation Between the Response and the Independent Variables

The fitted regression model showed a significant correlation between the response (i.e. OLBD Risk Probability) and all other four independent variables (i.e. vertical height, horizontal distance, load weight, and torso asymmetry angle) ($p < 0.05$). This correlation is rational, for with the increase of the distance between the individual and the origin of the lift (i.e. moment arm) more compression forces will act on the spine (Marras et al., 1997), thus, increasing the risk of OLBD. Also, it is logical that the OLBD Risk probability would increase with the increase of the load weight. The heavier the weight, the greater the forces acting on the spine, hence, the more potential the risk of the OLBD (Marras et al. 1997; Davis, Marras, & Waters, 1998). Additionally, one can expect an increase risk of injuring the back if the job involves torso asymmetry while lifting a heavy load. The more torso twisting involved, the greater muscle coactivation will occur (Marras & Mirka, 1992), increasing the spinal loading and the risk of OLBD.

5.5 Study Limitations

The findings from this study should be considered with respect to several limitations. First, the participants in this study were college students with little to no experience in MMH, where they may use different lifting strategies compared to workers with more MMH experience. Second, the LMM captured spine kinematics, only. Thus, the findings are limited to risk interpretations for the back, and not other body parts. Third, the lifting tasks were performed in a controlled laboratory setting that might not reflect the stress and other psychosocial factors present in the real workplace. Fourth, the participants in this study were male subjects, and no female participants were included. This may restrict the generalizability of the findings to males, only. Fifth, this study included two vertical zones out of four zones and two horizontal zones out of three zones of ACGIH TLV's lifting tables. Finally, this study used a lift rate of 240 lifts per hour. It is unknown how the OLBD Risk would be affected at much lower lift rate (e.g. 30 lifts per hour) or higher (e.g. 360 lifts per hour).

CHAPTER 6

CONCLUSION

This study addressed a void in the ACGIH TLV for lifting assessment method, in which it was unknown whether or not the TLV's for lifting with torso asymmetry less than 30˚ are suitable for lifting tasks with torso asymmetry greater than 30˚. The ACGIH TLV's for more frequent and long duration lifting tasks were investigated to determine the OLBD Risk level for lifting tasks within 30˚ torso asymmetry, the OLBD Risk level for lifting tasks beyond 30˚, and to recommend TLV's for lifting tasks greater than 30˚ (i.e. 45˚, 60˚, 75˚, and 90˚ torso asymmetry). The results have shown that the studied TLV's represented a low risk of OLBD for lifting tasks within 30˚ of torso asymmetry performed in knuckle to shoulder lifting zone at the two horizontal distances, and moderate risk in the mid-shin to knuckle lifting zone at the two horizontal distances. On the other hand, utilizing the ACGIH TLV's in lifting tasks with torso asymmetry greater than 30˚ represented moderate risk category in the four lifting zones.

The results have shown a significant effect of the vertical height, horizontal distance, load weight, and torso asymmetry angles upon the OLBD Risk probability value. The OLBD risk probability values were higher in the lifting tasks that originated in the mid-shin to knuckle zones compared to the knuckle to shoulder zone. Moreover, the OLBD Risk value was significantly different between the knuckle to shoulder zone (37.6%) and mid-shin to knuckle zone (48.6%) only at the intermediate horizontal zone. Also, it was significantly different between knuckle to shoulder zone and mid-shin to knuckle zone at torso asymmetry angles from 0˚ to 60˚.

Using the resulting prediction equation relating OLBD Risk to the study factors of horizontal zone, vertical zone, and torso asymmetry, lower TLV's were recommended for lifting tasks that resulted in moderate risk of OLBD for current TLV's. The new suggested TLV's should reduce the OLBD Risk level from moderate to low. No TLV's were recommended for lifting tasks in mid-shin to knuckle-extended zone for lifting with torso asymmetry greater than 30˚, for after applying the model prediction equation (Equation 4.1) the resulting TLV values were either zeros or negative, which suggests workers should not lift any weight in this zone if the lifting involves torso asymmetry greater than 30˚.

The major findings of this study are included:

- The greater the torso asymmetry angle, was the higher the OLBD Risk probability.
- The mid-shin to knuckle vertical lifting zone resulted in higher OLBD Risk value compared to the knuckle to shoulder vertical zone.
- The ACGIH TLV's in the knuckle to shoulder lifting zone with torso asymmetry less than 30˚ showed low OLBD Risk (i.e. OLBD Risk probability ≤ 30%).
- The ACGIH TLV's in the mid-shin to knuckle lifting zone with torso asymmetry less than 30˚ showed moderate OLBD Risk (i.e. 30% < OLBD Risk probability ≤ 70%).
- The ACGIH TLV's in the four lifting zones with torso asymmetry greater than 30˚ showed moderate OLBD risk (i.e. 30% < OLBD Risk probability ≤ 70%).
- Adjusted TLV's were developed for torso asymmetry angles between 30˚ and 90˚ to reduce the risk level to low risk for OLBD.
- Adjusted TLV's were developed for torso asymmetry angles of 45˚, 60˚, 75˚, and 90˚ to reduce the risk level to low risk for OLBD, for lifting tasks in the mid-shin to knuckle zone at the two horizontal distances.

- No TLV's were recommended in the mid-shin to knuckle-extended zone for torso asymmetry angles of 45˚, 60˚, 75˚, and 90˚, suggesting no lifting to or from these zones with torso asymmetry angles greater than 30˚.

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APPENDICES

APPENDIX A

IRB Consent Form-Page 1-2

Wichita State University
Institutional Review Board Approval
03/28/16 – 03/27/17

WICHITA STATE UNIVERSITY
COLLEGE OF ENGINEERING
Department of Industrial and Manufacturing Engineering

Purpose: You are invited to participate in a research study to evaluate the appropriateness of safe weight limits for lifting boxes identified by the ACGIH Threshold Limit Values (TLV) for Lifting assessment method when people twist their torso greater than 30 degrees (also referred to as torso asymmetry). We hope to determine if the safe weight limits identified by ACGIH are still considered safe at greater angles torso asymmetry.

Participant Selection: You were selected as a possible participant in this study because you are of the gender (male) and age range (19-30 years old) of participants we have identified to evaluate the ACGIH TLV for torso asymmetry greater than 30 degrees, and of the gender and age range that perform lifting tasks in occupations that would be evaluated by this lifting assessment method. Approximately 30 participants will be invited to join the study.

Explanation of Procedures: The study will be performed in the Human Performance and Design Lab in 02A Wallace Hall and is expected to last up to 1.5 hours. If you decide to participate, you will be asked to provide information about any conditions that may increase your risk due to lifting boxes (e.g., prior injuries, surgeries to shoulder, back, arms, legs). Affirmative answers will exclude you from participation. If you are able to participate, a back monitor will be placed on your back, which will measure the motion of your torso (forward bending, twisting, side bending) as you lift boxes. The back monitor will be attached to a waist harness and a shoulder harness. You will be asked to lift boxes of different weights from different origins (described below) with torso asymmetries of 0, 30, 45, 60, 75 and 90 degrees described below to a destination directly in front of you at waist level, performing four lifts in one minute at each torso asymmetry angle:

Origin 1: 7kg box, 75.4 cm above the floor and 50 cm horizontal distance from ankles
Origin 2: 2kg box, 75.4 cm above the floor and 70 cm horizontal distance from ankles
Origin 3: 9kg box, 110.5 cm above the floor and 50 cm horizontal distance from ankles
Origin 4: 5kg box, 110.5 cm above the floor and 70 cm horizontal distance from ankles

Discomfort/Risks: There will likely be little to no risk of discomfort from wearing the back monitor as it provides little resistance to motion of the torso and weighs less than 2kg. You may experience delayed muscle soreness to your shoulders or low back if you are not accustomed to lifting boxes. However, the weights selected to lift are considered to be close to low risk by the ACGIH TLV Lifting method, and should soreness occur it will likely dissipate in approximately 48 hours.

Benefits: There will likely be no direct benefit to the human participants who participate in this study. The benefits to scientific knowledge may be the determination if the TLVs (approximate 'safe' weights) identified by the ACGIH TLV for Lifting method are appropriate with respect to lifting with torso asymmetry angles greater than 30 degrees.

Confidentiality: Every effort will be made to keep your study-related information confidential. However, in order to make sure the study is done properly and safely there may be circumstances where this information must be released. By signing this form, you are giving the research team permission to share information about you with the following groups:

IRB Consent Form-Page 2-2

Wichita State University
Institutional Review Board Approval
03/28/16 – 03/27/17

- Office for Human Research Protections or other federal, state, or international regulatory agencies;
- The Wichita State University Institutional Review Board;

The researchers may publish the results of the study. If they do, they will only discuss group results. Your name will not be used in any publication or presentation about the study.

Compensation or Treatment for Research Related Injury: Wichita State University does not provide medical treatment or other forms of reimbursement to persons injured as a result of or in connection with participation in research activities conducted by Wichita State University or its faculty, staff, or students. If you believe that you have been injured as a result of participating in the research covered by this consent form, you can contact the Office of Research and Technology Transfer, Wichita State University, Wichita, KS 67260-0007, telephone 316-978-3285.

Refusal/Withdrawal: Participation in this study is entirely voluntary. Your decision whether or not to participate will not affect your future relations with Wichita State University. If you agree to participate in this study, you are free to withdraw from the study at any time without penalty.

Contact: If you have any questions about this research, you can contact me at: Khaled Hafez, kahafez@wichita.edu. You can also contact Dr. Michael Jorgensen, 204 Engineering Building, Wichita State University, 316-978-5904, michael.jorgensen@wichita.edu. If you have questions pertaining to your rights as a research subject, or about research-related injury, you can contact the Office of Research and Technology Transfer at Wichita State University, 1845 Fairmount Street, Wichita, KS 67260-0007, telephone (316) 978-3285.

You are under no obligation to participate in this study. Your signature below indicates that:

- You have read (or someone has read to you) the information provided above,
- You are aware that this is a research study,
- You have had the opportunity to ask questions and have had them answered to your satisfaction, and
- You have voluntarily decided to participate.

You are not giving up any legal rights by signing this form. You will be given a copy of this consent form to keep.

____
Printed Name of Subject

____________________________________ ________________
Signature of Subject Date

____
Printed Name of Witness

____________________________________ ________________
Witness Signature Date

APPENDIX B

Data Collection Sheet

Subject Name	Sex	Weight	Height	Knee	Elbow	Waist	Age

Load Weight	Task	Function	Moment Arm (cm)										
			1			2			3			4	
			O	D		O	D		O	D		O	D
10 lb	Elbow-Extended0	F1											
	Elbow-Extended15	F2											
	Elbow-Extended30	F3											
	Elbow-Extended45	F4											
	Elbow-Extended60	F5											
	Elbow-Extended75	F6											
	Elbow-Extended90	F7											
20 lb	Elbow-Intermediate0	F1											
	Elbow-Intermediate15	F2											
	Elbow-Intermediate30	F3											
	Elbow-Intermediate45	F4											
	Elbow-Intermediate60	F5											
	Elbow-Intermediate75	F6											
	Elbow-Intermediate90	F7											
5 lb	Knee-Extended0	F1											
	Knee-Extended15	F2											
	Knee-Extended30	F3											
	Knee-Extended45	F4											
	Knee-Extended60	F5											
	Knee-Extended75	F6											
	Knee-Extended90	F7											
15 lb	Knee-Intermediate0	F1											
	Knee-Intermediate15	F2											
	Knee-Intermediate30	F3											
	Knee-Intermediate45	F4											
	Knee-Intermediate60	F5											
	Knee-Intermediate75	F6											
	Knee-Intermediate90	F7											